$F_2^{b\bar{b}}$ measurement with inclusive secondary vertices at ZEUS

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Abstract. The production of beauty quarks in deep inelastic scattering has been measured with the ZEUS detector using the full HERA II data set. The beauty content in events with a jet was determined using the decay length significance and invariant mass of inclusive secondary decay vertices. Differential cross sections as a function of Q^2, Bjorken x, E_T^{jet} and η^{jet} were measured and compared to theoretical predictions. The open beauty contribution to the proton structure function F_2 was extracted.

Keywords: Beauty production, proton structure, QCD, HERA, ZEUS
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INTRODUCTION

The production of beauty quarks at HERA, an electron-proton collider with a center-of-mass energy of 318 GeV, is interesting in several aspects. The large mass of b-quarks enables perturbative QCD calculations to be performed. In the lowest order, heavy quarks are produced via boson-gluon fusion, hence this process is sensitive to the gluon content of the proton and provides a means to check the consistency of the gluon density function in the proton as determined from inclusive data. The study of beauty production can also shed light on the so called multiple-hard-scale problem: the high beauty mass is not the only possible hard scale in the process; at high photon virtuality or beauty quark momenta, the perturbative expansion diverges due to logarithmic terms. Several schemes exist to perform perturbative calculations, such as massive, massless or mixed schemes. They treat differently mass effects and hence the multi-scale problem.

This work reports a measurement of the beauty-jet production differential cross-sections and extraction of the beauty contribution to the proton structure function, $F_2^{b\bar{b}}$.

EXPERIMENTAL PROCEDURE

After production in the hard interaction, beauty quarks hadronize into bottom hadrons, which due to their long lifetime travel detectable distances before they decay. This feature allows the usage of lifetime-tagging techniques in order to distinguish beauty quark production from background processes. The measurement reported here employs an inclusive secondary vertex method as described below.

The kinematic region considered was:

- $5 < Q^2 < 1000\ \mathrm{GeV}^2$, where Q^2 is the negative 4-momentum squared of the virtual photon (virtuality);

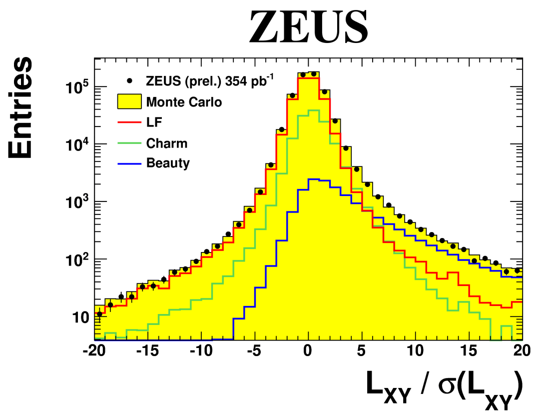

FIGURE 1. Decay length significance for data, signal (beauty) and background (light flavours and charm) Monte Carlo for vertex mass in range $[2,6]$ GeV. The Monte Carlo distributions were scaled according to the fit results (see text).

- $0.02 < y < 0.7$, where y is the fraction of the electron energy lost in the interaction in the proton rest frame (inelasticity);
- jets were required to have $E_T > 5$ GeV and $-1.6 < \eta < 2.2$.

Tracks belonging to each jet were considered. If at least two tracks with $p_T > 0.5$ GeV were found within the cone of $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < 1$ w.r.t. to the jet axis, a secondary vertex was fitted, otherwise the jet was discarded. For each fitted secondary vertex, its decay length significance was calculated using the formula: $S = L_{xy}/\sigma(L_{xy})$, where L_{xy} is the decay length projected onto the jet axis in the plane perpendicular to the beam, and $\sigma(L_{xy})$ is its uncertainty. The decay length signifance was used as a discriminating variable. The distributions for data and beauty, charm and light flavour (LF) Monte Carlo are shown in Fig. 1. The dominant contribution comes from LF production. This background was reduced by mirroring, that is subtraction of the negative significance part from the positive part. After the mirroring, template fits were performed to obtain the beauty fraction in the data. The secondary vertex mass was used in addition for separation, as it is larger for b-quarks than for charm or LF: the fits were done simultaneously in three vertex mass bins. The procedure was repeated for each bin in the differential cross-sections. $F_2^{b\bar{b}}$ was determined by extrapolation of $Q^2 - x$ double-differential cross-sections using NLO QCD calculations described below.

THEORY PREDICTIONS

QCD NLO calculations were performed with the HVQDIS [1] program (fixed-flavour number scheme). The ZEUS-S and ABKM NLO [4] parton density functions (PDF) were used. The renormalization and factorization scales were set to $\mu_R = \mu_F = \sqrt{Q^2 + 4m_b^2}$. The mass of the beauty quark was set to $m_b = 4.75$ GeV for the ZEUS-S PDF set and $m_b = 4.5$ GeV for the ABKM PDF set. As HVQDIS provides parton tree level cross-sections, hadronization and QED corrections were applied as determined from the RAPGAP Monte Carlo [2]. Uncertainties on the theory predictions were estimated by varying HVQDIS settings: μ_R and μ_F independently by factors 0.5 and 2; m_b to 4.5 and 5 GeV.

RESULTS

Figure 2 shows measured differential cross sections as a function of x, Q^2, E_T^{jet} and η^{jet} together with NLO QCD calculations. Predictions from RAPGAP Monte Carlo (LO+parton shower), scaled according to the fit are also shown. The overall agreement between data and theoretical predictions is reasonable, although the data tend to lie above the NLO predictions. Figure 3 shows the contribution to the proton structure function $F_2^{b\bar{b}}$ as a function of x for different Q^2 regions. The data are compared to NLO predictions (HVQDIS) and to (partial) NNLO calculations by the ABKM group. Both describe the data quite well, with NNLO slightly preferred over NLO. In Fig. 3 we also compare these results to previous measurements of $F_2^{b\bar{b}}$ [3] as well as other theory predictions. The precision of this measurement is better than previous results from HERA.

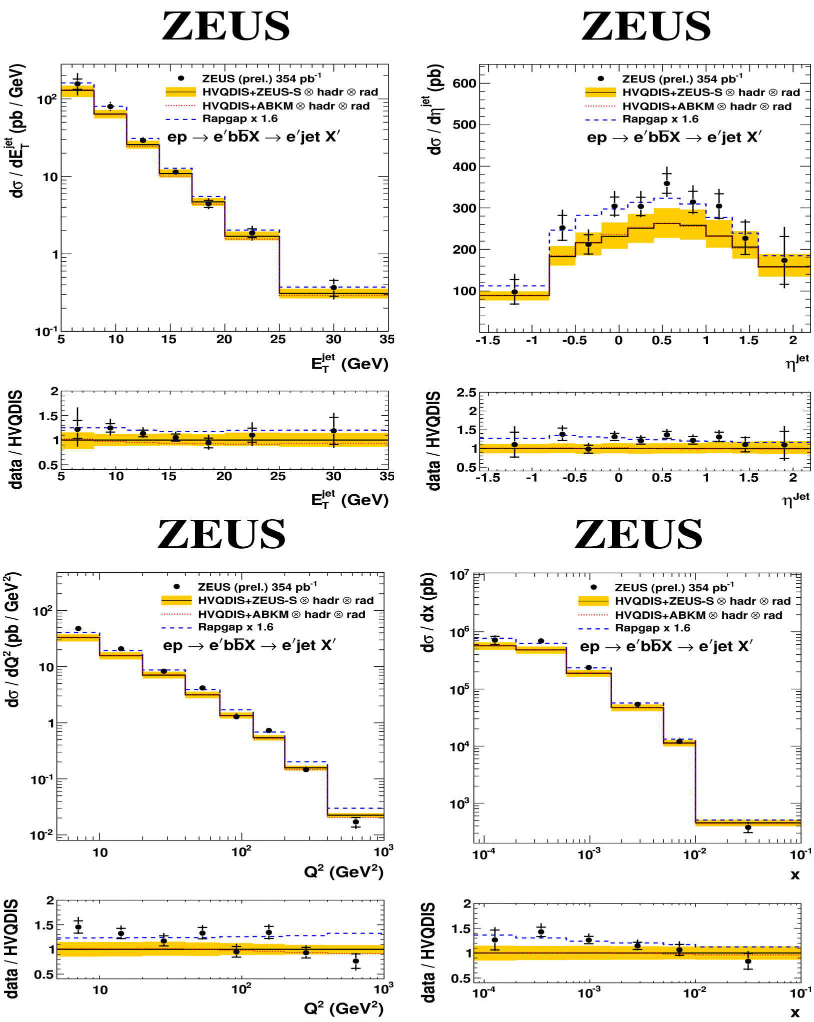

FIGURE 2. Measured differential cross-sections as a function of E_T^{jet}, η^{jet}, Q^2 and x

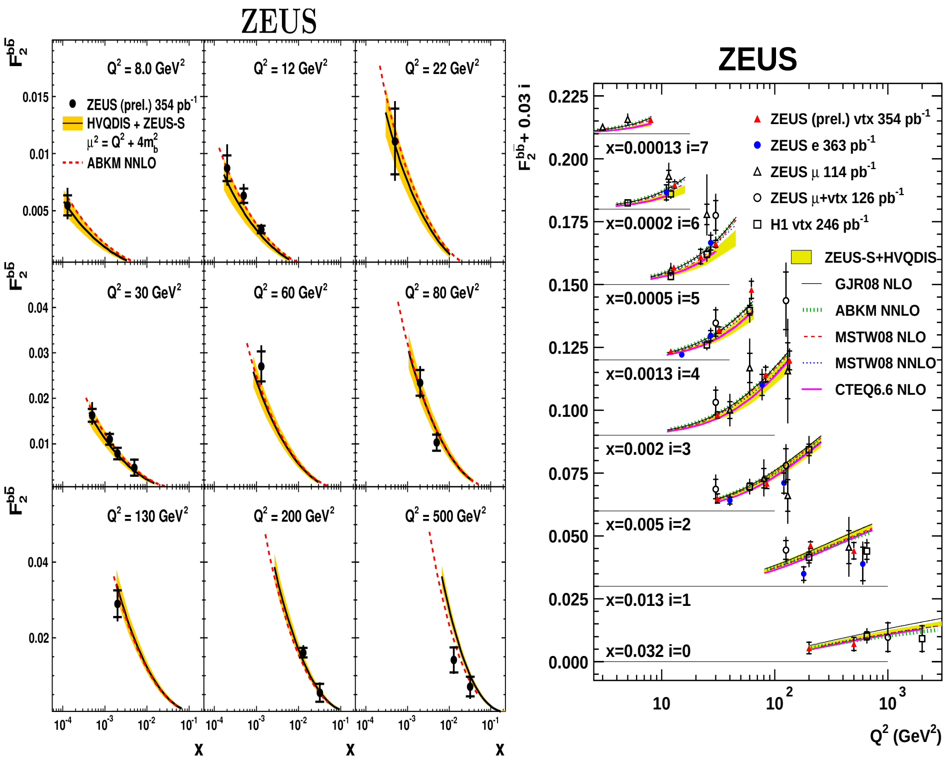

FIGURE 3. $F_2^{b\bar{b}}$ results compared to previous measurements and QCD predictions.

CONCLUSIONS

The measurement of beauty production differential cross-sections in deep inelastic scattering and beauty contribution to the proton structure function, $F_2^{b\bar{b}}$, has been reported. The overall agreement between data and QCD calculations is reasonable, with the theory lying slightly below the data. NNLO QCD predictions tend to describe the data somewhat better. The precision of $F_2^{b\bar{b}}$ is improved with respect to the previous measurements due to the inclusive nature of analysis.

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